[Impacts of Genetic Variation and Silvicultural Treatments on Loblolly Pine Water Use]

by

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*Masters project proposal submitted in partial fulfillment of the*

*requirements for the Master of Environmental Management degree in*

*The Nicholas School of the Environment of*

*Duke University*

[I/WE] certify the following:

Does this proposed MP involve human subjects research? \_\_\_ Yes \_\_Ⅹ\_ No

If yes, has an approved IRB protocol been obtained? \_\_\_ Yes \_\_\_ No

Does this proposed MP involve the use of animals in research? \_\_\_ Yes \_\_Ⅹ\_ No

If yes, has an approved IACUC protocol been obtained? \_\_\_ Yes \_\_\_ No

Does this proposed MP involve signing a non-disclosure agreement? \_\_\_ Yes \_Ⅹ\_\_ No

If yes, does the advisor have a signed copy? \_\_\_ Yes \_\_\_ No

Student Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_

Advisor Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_

**Part I: Scope of Work**

Introduction

Forest lands are shrinking rapidly due to anthropological development, primarily losing to agricultural land conversion necessary for growing population (FAO & UNEP, 2020). Aside from the biological, ecological and spiritual values lost along with deforestation, the world continues to increase its demand for wood (FAO, 2009). The total volume of forest growing stock, however, remains relatively stable over the last three decades (FAO, 2020), meaning forests are required to either be more densely stocked or possess higher productivity. As the most abundant softwood species in the U.S. and the most commercially important timber species in the South (Brender, Belanger, & Malac, 1981), loblolly pine (*Pinus taeda,* or *P. taeda*) supports the timber industry generously and contributes abundant above-ground biomass at 2.1 billion tons in 2017 (Oswalt et al., 2019). Native to southeastern U.S., *P. taeda* exhibits higher productivity and higher carrying capacity outside of its native range (Samuelson et al., 2013; Shimizu & Sebbenn, 2008), showing great economic and ecological potential. Numerous theories have been developed intending to explain such variability in the hope of finding efficient methods of enhancing *P. taeda* yield. The factors considered in previous studies include but not limit to: environmental settings (Wallinger, 2002), stockability (DeBell, Harms, & Whitesell, 1989), management intensity (Borders & Bailey, 2001), spacing regimes (Cardoso et al., 2013), genetic variation (de Oliveira et al., 2018), and previous land use (Souza et al., 2022). There has not been a definite answer to the question yet.

Brender, E.V., Belanger, Roger, P., & Malac, B.F. (1981). *Choices in Silviculture for American Forests* (pp. 144-163). Society of American Foresters.

Borders, B. E., & Bailey, R. L. (2001). Loblolly pine—pushing the limits of growth. *Southern Journal of Applied Forestry*, *25*(2), 69-74.

Cardoso, D. J., Lacerda, A. E. B., Rosot, M. A. D., Garrastazú, M. C., & Lima, R. T. (2013). Influence of spacing regimes on the development of loblolly pine (Pinus taeda L.) in Southern Brazil. *Forest Ecology and Management*, *310*, 761-769.

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Shimizu, J. Y., & Sebbenn, A. M. (2008). Espécies de Pinus na silvicultura brasileira. *Pinus na silvicultura brasileira. Colombo: Embrapa Florestas*, 49-74.

Wallinger, S. (2002). Intensive forest management: growing wood and preserving biodiversity in the US South and Brazil. *Forest Operations Review*, 5-10.

We want to further understand *P. taeda* physiology from an aspect less frequently discussed: water use.

Transpiration is defined as the amount of water used in this process (Hanrahan, 2011). It can be either estimated or directly measured. Gauged watershed method simply subtracts runoff from precipitation to generate transpiration (Hasenmueller & Criss, 2013,); energy balance methods such as the Penman-Monteith Equation considers transpiration as component of an integrated mass-transfer system and estimates transpiration from stomatal conductance (Monteith & Unsworth, 1990); the Eddy covariance and flux gradient method calculates flux by computing the covariance between fluctuations in vertical wind velocity and fluctuations of transferred properties such as heat and moisture (Lee & Law, 2004); there are also various hydrological models for estimating transpiration (Vose & Swank 1992). On the other hand, direct measurements of individual tree sap flow provides the basis for above methods and generates most reliable results (Vose et al., 2003). Granier (1985) discovered sap flux density (sap volume/sapwood area/timeY) as a function thermal conductivity (Fd = 119 \*k1.231). A thermal sensor with two probes, one electrically heated at lower position I and one at ambient temperature at upper position, is inserted into the sapwood of a tree trunk where water transportation occurs (Liu, Urban & Zhao, 2004). Because tree sap flows upward, the heat dissipated by the lower probe affects the temperature of the upper probe. The temperature differences between the two probes can therefore be transformed into sap flux density, or how much water is passing through xylem. From the point measurements, we can escalate it to tree-level and stand-level transpiration using sapwood area.

Water moves passively from soil into the atmosphere through the root, xylem, and shoots of trees, carrying necessary nutrients and supports photosynthesis (Sinha, 2004). Plant transpiration is an integrate part of local and global carbon and hydrological cycle (Jasechko et al., 2013).It responds to both biotic and abiotic factors including individual tree crown architecture, planting density, water content in the air, and soil moisture.

Transpiration changes with tree characteristics as the conductance of water flow varies with each tree’s morphology and physiology (Kimball, 2007). In this MP, we will test two biotic factors that theoretically affect transpiration: crown architecture and planting density. Crown architecture, or ideotype, is restricted to consistent morphological expressions including crown size, density, branching patterns, angle of leaves relative to each other, etc. (Dickmann, 1985; Martin, Johnsen, & White, 2001). Although it is innate with a tree’s genetic entry, the traits can be influenced by environmental factors (Carbaugh, 2015). Crown ideotype largely defines leaf area, an important measure of plant growth and productivity as it determines light interception and transpiration (Vose & Allen, 1988; Wright et al., 2004).Spacing is a common silvicultural practice to meet various management objectives. Spacing regimes affect transpiration by manipulating the interactions between trees. High planting density promotes competition and reduces individual tree sizes (Carlson et al., 2009; Harms, Whitesell, & DeBell, 2000), thus encourages narrow crown development—vice versa for low planting density. Past study has proven that low planting density of *P. taeda* yields greater diameter branches and stem, foliage and branch biomass, leaf area and canopy density, longer-lived crown, lower height to live crown and lower foliage to branch mass ratio comparing to high planting density (Albaugh et al., 2019; Akers et al., 2012).

Water movement follows a high to low water potential gradient, moving from wet to dryer places, the low water potential in the ambient air becomes the primary driving force deciding how much water is pulled out through leaf stomata (Freeman, 2014). This water potential, or how “wet/dry” the air is, can be expressed as vapor pressure deficit (VPD, expressed as the difference between relative humidity and fully saturated air) (Lawrence, 2005).

Water availability is another critical consideration especially when we are facing the challenge of climate change, as drought is the primary factor contributing to reduced productivity and increased mortality (Allen et al., 2010). Zhao and Running (2009) estimated a drought-induced reduction of 0.55 petagram carbon in global net primary productivity from 2000 to 2009. Plants can cope with restricted water supply by closing their stomata to stop transpiring, at the same time pausing photosynthesis (Agurla et al., 2018). Permanent cavitation of water-transporting xylems can occur as a severe consequence of extreme water potential difference, consequently reduces a tree’s ability to conduct water, to grow and to survive (Zhang et al., 2016). Thus transpiration can be affected by stomata closure drastically under different water availabilities, expressed as soil moisture measurements.

Goals & Objectives

This Master’s Project (MP) exists as part of a larger project collaborated between United States Forest Service (USFS), North Carolina State University, Virginia Tech, and Federal University of Santa Catarina, Brazil. The larger study is a long-term silviculture (three planting densities), site (North Carolina Coastal Plain, Virginia Piedmont, and Brazil), and genetic (six genotypes) experiment in efforts to further understand *P. taeda* physiology. This Master Project focuses on the Virginia site intending to assess the variation in *P. taeda* water use.

Here in this MP, four genetic entries are chosen to represent different crown architectures. We are interested in how water costs might differ for each ideotype and planting density, along with their interactions; we will evaluate whether there is a difference in how each treatment group respond to VPD. In addition, we are also interested in how *P. taeda* transpiration responds to VPD under different soil moisture regimes between treatments.

**Goals**:

* To enhance the understanding of *P. taeda* physiology

**Objective**:

* To understand how *P. taeda* transpiration is affected by crown architecture and planting density, accounting for additional environmental parameters, in efforts to answer the following sub questions:
  1. Does transpiration vary with genotypes and planting densities?
  2. Does transpiration respond to VPD differently with different genotypes and planting densities?.
  3. Does response to VPD vary with different levels of soil moisture between genotypes and planting densities?

Methods and Sources of Support

**Study Area**

Three experimental sites were established in the larger study, including one in the Piedmonts (Reynolds Homestead Center, Virginia, northern edge of *P. taeda* range), one located on the coastal plain (Bladen lakes, NC, a typical *P. taeda* site), and one far away from *P. taeda* range (Renova Forest, Brazil). The data analyzed in this MP solely came from the Piedmont site in Virginia. Although slightly outside of the northern range of *P. taeda*, the species has established successfully in the Piedmont.

**Data Source & Experiment Setup**

USFS research biological scientist Christopher Maier, also my additional MP advisor, has provided the data that make this project possible.

The experiment is a block plot with a split-split plot design replicated 4 times (4 systems); silviculture (low/high intensity) is the main plot and spacing and genetic entry are the split plots (Albaugh et al., 2018). With a total of eight plots, each plot contains one treatment (one clone planted at one density). The experiment was set up as the chart below:

Table 1. Experimental Setup

|  |  |  |
| --- | --- | --- |
| System | Genotype (crown architecture variation) | Density (trees/acre) |
| 1 | C4 | 750 |
| OP | 250 |
| 2 | C4 | 250 |
| OP | 750 |
| 3 | C2 | 250 |
| C3 | 250 |
| 4 | C3 | 750 |
| C2 | 750 |

Where according to Carbaugh (2015), OP stands for an open-pollinated family and C refers to clones. C3 is considered narrow crown genotype whereas C2 and C4 are considered broad crown genotypes. The narrow crown genotype possesses smaller branch diameter, branch length, and crown volume than the broad crown genotypes. Within the broad crown genotypes, C4 has a slightly larger crown volume than C2. The OP family share similar branch characteristics to the broad crowned clones with a crown volume in between of broad and narrow crowned clones.

Within each treatment plot, eight trees are sapflux trees inserted with a pair of probes inserted from 0-20 mm (shallow) on the north and south side of the tree; two trees in each plot had an additional probe inserted from 20-40mm (deep).

The stand was planted in 2009, and the data for this MP were collected continuously for two years, at stand age 8-9.

Additional data related to the weather parameters were either directly recorded from the site or obtained from on-site weather station.

**Workflow**

Data Cleaning (completed): The 15-minute-interval raw k-values generated from thermal probes have been transformed into sap flux density using the Granier’s Equation. Data have been visually presented and checked for error and interesting patterns.

Small gaps (<48 entries, or half day) of individual probes have been filled in with simple linear regression between probes for each 15-minute entry. The transformed sap flux of individual data points was scaled up temporally (daytime, 24-hour period). It will also be scaled up spatially to stand level transpiration using plot-specific sapwood area. Gaps bigger than 48 entries were gap-filled using simple linear regression between probes for each daily sum.

Data analysis (in progress): The true means of treatments will be compared using a Two-Way ANOVA (Sap flux~ genotype + density). Then, I will assess the differences of responses to VPD between treatments using a linear model (Sap flux ~ VPD + 8 treatment groups), and how the responses to VPD change with soil moisture between treatments with another linear model (Sap flux ~ VPD + 8 treatment groups + 2 soil moisture levels).

Analysis phases: Phase I of the analysis is to find and test the best approach with one month’s data (nearly completed). Phase II is to expand this approach to a larger range of data—as large as time permits.

Data would be analyzed primarily using Microsoft Excel and R. Limited python will be applied.

Expected Results and Format of Report

The study aims to model treatment differences in terms of *P. taeda* water use, in the hope of contributing to further studies within the larger project. This study will identify water use efficient *P. taeda* genotype(s) and help direct future studies that ultimately try to explain the differences in *P. taeda* productivity between locations.

The result of this project will be delivered in the format of a report and a presentation. The report shall be written professionally and scientifically; it will be submitted to the Nicholas School as the final MP report. A presentation will be given to the Nicholas School audiences and/or any individual interested in such topic during the MP Symposium on December 1st, 2022. The presentation shall be relatively succinct and intelligible to the general public, including sufficient background information and appealing graphic presentations of the study outcome.

The anticipated outcome, in addition to MP, is a potential manuscript submitted to a top professional journal.

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Faculty

**Ram Oren** (primary advisor), Nicholas School of the Environment & Pratt School of Engineering, Duke University

**Christopher Maier** (additional advisor), Research Biological Scientist/Team Leader at Southern Research Station, U.S. Forest Service

**Part II: Project Timeline**

|  |  |
| --- | --- |
| *Time* | *Action/Due* |
| Academic year 2020-21  *Initial setup* | * Accepting project as assistantship * Developing advisory team and plan for MP * Complete supplemental reading related to the project:   + Previous publications on the project   + Additional papers on tree physiology (especially on sap flux) * Understand study design and background information * Data cleaning |
| Fall 2021  *Analysis* | * Data exploration: visually present the data and look for interesting patterns or abnormities * Eliminate errors and gap fill * Narrow down analysis direction and statistical methods; devise the scope of MP * Project prospectus due on 10/29 |
| Spring 2022  *Analysis* | * Work plan due on 2/1 * Literature review * Re-run data cleaning procedure with newly possessed coding skills * Statistical analysis * Project status presentation |
| Summer 2022 | * Statistical analysis * Expanding analysis to larger range of the dataset as much as I can. Ideally perform the analysis on an entire year of data |
| Fall 2022  *Wrap-up and writing* | * Wrap-up analysis * Written draft of Final Report due on 9/30 * Develop good visual presentations of the study outcome * Revised draft due on 10/31 * 10-Line Abstract due to Student Services on 11/18 * Submission of final MP to iThenticate for scanning on 11/28 * Present MP (Symposium) on 12/1 * Final MP due on 12/8   + Upload to DukeSpace   + Submit signed executive summary to Student Services via the DukeBox Upload Window |

**Part III: Team Charter**

Team Roles and Responsibilities

|  |  |  |
| --- | --- | --- |
| Member | Role/Title | Responsibilities/Expectations |
| Azura Liu | *MEM-ESC/MF Student* | * Conduct analysis and complete the MP * Schedule meetings and ensure communication |
| Ram Oren | *Master's Advisor,*  *NSOE Professor/Faculty* | * Primary advisor * Assist student with administrative requirements * Provide guidance on study design and direction * Give feedback and insight on analysis completed by student |
| Christopher Maier | *Member of the Advisory Team,*  *USFS Research Biological Scientist* | * Additional advisor * Supply data and background information necessary for the project * Provide guidance on study design and direction * Give feedback and insight on analysis completed by student |

Regular Meeting Schedule

The MP team meets on a weekly to bi-weekly basis based on the progress student has made. Student meets one or both advisors according to each member’s schedule.

Team Expectations

Team members will communicate efficiently through email, the primary method of communication. Meetings are conducted primarily via Zoom, but the team tries to meet in person at NSOE or USFS research station as possible.

Team Purpose and Mission

The team aims to complete the MP in reasonable timeframe. Beyond the MP requirement, we will take advantage of the marvelous dataset and explore as much as possible. The outcome of the study shall aid understanding in loblolly pine physiological mechanisms and production.

**Top Prioritieis and Goals**: As someone who never performed research before, the student takes the project as a valuable learning experience, understanding the logic and obtaining necessary skills for research as diving deeper. The top priority and goal of the advisors is to provide appropriate guidance and advice so student can learn efficiently and yield a high-quality MP in time.

Team Cohesion and Conflict Resolution

When conflicts emerge, team members will communicate honestly and openly regarding responsibilities. If there are disagreements in analysis approaches, statistical methods, etc., the team members will each present their thoughts and decide on what is best. Additional help from other faculties (e.g. Statistics professor) can be sought if agreement cannot be achieved.

**Additional Resources:** available at Duke Graduate School Student Resources ([https://gradschool.duke.edu/student-life/student-resources](about:blank)